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Have mirror planets been observed?

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Abstract

Over the last few years, several close orbiting (~ 0.05 AU) large mass planets ($M \sim M_{Jupiter}$) of nearby stars have been discovered. Their existence has been inferred from tiny doppler shifts in the light from the star. We suggest that these planets may be made of mirror matter. We also suggest that some stars such as our sun may also have a similar amount of mirror matter, which has escaped detection.

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Over the last few years a number of planets orbiting nearby stars have been discovered (for a review and references see [1]). Their existence has been inferred from tiny doppler shifts in the light from the star due to its orbit around the center of mass. The periodicity and magnitude of the doppler shifts can be used to determine the mass and orbit of the planet.

Surprisingly about half a dozen large planets (ie. with Jupiter sized masses or larger) have been found which have orbits very close to the star (between 0.04 to 0.06 AU). We summarize the data in Table 1 which lists all of the confirmed planets with orbits less than 0.1 AU.

STAR	*MASS (J)*	*SEM-MAJ AXIS (AU)*	*PERIOD (d)*	*ECC*
HD75289 28.94 pc	0.42	0.046	3.51	0.054
51 Peg 15.36 pc	0.47	0.05	4.23	0.0
HD187123 49.92 pc	0.52	0.042	3.097	0.03
Ups And 13.47 pc	0.71	0.059	4.617	0.034
HD217107 19.72 pc	1.28	0.04	7.11	0.14
Tau Boo 15.60 pc	3.87	0.0462	3.3128	0.018
HD98230	37	~ 0.06	3.98	0.00
HD283750	50	~ 0.04	1.79	0.02

Table Caption: Table obtained from Ref. [1] showing the mass (in units of Jupiter mass), Semi-Major axis, period (in days) and eccentricity of all of the confirmed planets with orbits less than 0.1 AU.

Whilst the doppler shift detection technique is quite sensitive to large mass planets with close orbits, the fact that any such planets with these properties exist at all is unexpected. To date none of these nearby planets has been seen directly, however this should be possible in the future provided that they are made of ordinary matter. We believe that an interesting alternative possibility exists and that is that these close orbiting large planets might be made of mirror matter. [This has also been suggested independently by Volkas [2].].

The existence of mirror matter is well motivated from a particle physics point of view, since these particles are predicted to exist if parity and indeed time reversal are unbroken symmetries of nature [3,4]. The idea is that for each ordinary particle, such as the photon, electron, proton and neutron, there is a corresponding mirror particle, of exactly the same mass as the ordinary particle. For example, the mirror proton and the ordinary proton have exactly the same mass[†]. Furthermore the mirror proton is stable for the same reason that the ordinary proton is stable, and that is, the interactions of the mirror particles conserve a mirror baryon number. The mirror particles are not produced in Laboratory experiments just because they couple very weakly to the ordinary particles. In the modern language of gauge theories, the mirror particles are all singlets under the standard $G \equiv SU(3) \otimes SU(2)_L \otimes U(1)_Y$ gauge interactions. Instead the mirror particles interact with a set of mirror gauge particles, so that the gauge symmetry of the theory is doubled, i.e. $G \otimes G$ (the ordinary particles are, of course, singlets under the mirror gauge symmetry) [4]. Parity is conserved because the mirror particles experience $V + A$ mirror weak interactions and the ordinary particles experience the usual $V - A$ weak interactions. Ordinary and mirror particles interact with each other predominately by gravity only.

At the present time there is a range of experimental evidence supporting the existence of mirror matter. Firstly, it provides a natural candidate for dark matter, which might be mirror stars (and mirror dust, planets etc) [5]. There is an interesting possibility that these mirror stars have already been detected experimentally in the MACHO experiments [6]. Secondly, ordinary and mirror neutrinos are maximally mixed with each other if neutrinos have mass [7]. This nicely explains the solar and atmospheric neutrino anomalies. The idea is also compatible with the LSND experiment [7]. Interestingly, maximal ordinary - mirror neutrino oscillations do not pose any problems for big bang nucleosynthesis (BBN) and can even fit the inferred primordial abundances better than the standard model [8].

Of course due to the nature of mirror matter, its existence is difficult to rigorously prove (or disprove). If many nearby stars have close orbiting mirror planets then this should help establish the existence of mirror matter. Mirror planets cannot be seen directly because they cannot reflect the light from the star. This is a definite and in fact testable prediction of our mirror planet hypothesis. Another implication of the mirror planet hypothesis is that it may not be possible to detect the change of brightness when the planet occults the star (i.e. when the planet passes between the star and its line of sight as seen from the earth). This is just because mirror matter may be completely transparent to ordinary light! [‡]. Another implication of the mirror planet hypothesis is that the orbital plane of the mirror planets

[†]The mass degeneracy of ordinary and mirror matter is only valid provided that the parity symmetry is unbroken, which is the simplest and theoretically most attractive possibility. For some other possibilities, which invoke a mirror sector where parity is broken spontaneously (rather than being unbroken), see Ref. [9].

[‡]Actually it is possible that there is a small electromagnetic coupling between ordinary and mirror matter arising from photon - mirror photon kinetic mixing (see latter discussion). This small interaction can potentially make the mirror planet opaque (this will obviously depend on the strength of this interaction, i.e. the parameter ζ in Eq.(1) below, on the frequency of light and the amount and chemical composition of the mirror planet). Also, it should be noted that the mirror planet might be only partially opaque leading to absorption lines. This could provide a clear signal that the planet is made of mirror matter. Amusingly, if this could be observed, then it might be possible to determine the chemical composition of the mirror planet.

may be in a completely different plane to ordinary planets. For example, the star Upsilon Andromedae has three confirmed Jovian planets. One with a close orbit (listed in the fourth row of the table) and two more distant planets with orbits 0.83 AU and 2.5 AU [1]. If the two distant planets are made of ordinary matter than it is likely that the these two planets should orbit in a different plane to the close orbit planet if this is a mirror planet. This is just because ordinary and mirror matter interacts with each other predominately by gravity only.

If these close orbiting planets are made of mirror matter, then a number of questions naturally arise. Firstly there are arguments which suggest that ordinary and mirror matter should be segregated on relatively large scales. A scale of 10^5 stars was estimated in Ref. [10]. This was assuming that ordinary and mirror matter interact only gravitationally (along with a number of other assumptions which may not always be valid). However, it was pointed out in Ref. [11,12,4] that ordinary and mirror matter can interact weakly due to photon kinetic mixing. In field theory this is described by the interaction Lagrangian density

$$\mathcal{L} = \zeta F^{\mu\nu} F'_{\mu\nu}, \tag{1}$$

where $F^{\mu\nu}$ ($F'_{\mu\nu}$) is the field strength tensor for electromagnetism (mirror electromagnetism). This type of Lagrangian term is gauge invariant and renormalizable and can exist at tree level [13,4] or maybe induced radiatively in models without $U(1)$ gauge symmetries (such as grand unified theories) [11,12,14]. The effect of ordinary photon - mirror photon kinetic mixing is to give the mirror charged particles a small electric charge [11,12,4]. That is, they couple to ordinary photons with charge ζe. This small non-gravitational force will allow some ordinary matter - mirror matter collisions which can dissipate energy and help ordinary stars attract a significant ('significant' means of the order of 0.1 percent by mass) amount of mirror matter during their formation.

Of course one may wonder why some stars have mirror companions and not other stars. In particular their is obviously no such large mirror planet orbiting our sun. One possibility is that all stars in our region of the galaxy attracted a significant amount of mirror matter during their formation. However for some of these stars (including our sun) it might be that the mirror matter was so close to the ordinary matter that it was either destroyed by tidal forces or the tidal forces prevented it from forming in the first place. Indeed, a mirror (or ordinary) planet would be destroyed by tidal forces when its radius is within the Roche limit, given by [15]:

$$r < f_R \left(\frac{\bar{\rho}_s}{\bar{\rho}_p} \right)^{1/3} R_s, \tag{2}$$

where $\bar{\rho}_s,\ \bar{\rho}_p$ are the average densities of the star and planet respectively and R_s is the radius of the star. Also $f_R \simeq 2.5$ [15]. If the mirror planet is close enough to break apart by the tidal forces then one may be left with rings of mirror matter surrounding the star. This might be similar to the rings of saturn which may have formed from the tidal break up of a moon or moons. Naturally we would expect much of the mirror ring material to have migrated to the center of the sun by either gravitational dissipation [16], collisions of the orbiting mirror particles with themselves and/or through the small possible non-gravitational force arizing form photon-mirror photon kinetic mixing. The latter effect can easily be estimated and any mirror matter within the radius of the star would have migrated to the center provided that $\zeta \gtrsim 10^{-15}$. This is consistent with the experimental and BBN bounds on ζ [12,17,18] which imply that $\zeta \lesssim 10^{-6} - 10^{-8}$.

In summary, we have suggested that the close orbiting planets discovered in nearby stars can be plausibly explained in terms of mirror matter. Stars (such as our sun) without close orbit mirror planets may also have a significant amount of mirror matter which has broken up under the tidal forces. In this case, most of this mirror matter would be expected to have migrated to the center of the sun, although some mirror material may also exist in the form of mirror rings (similar to the rings of saturn, except they are made of mirror matter). This mirror planet hypothesis will be testable in future experiments.

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